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IDENTIFICATION OF ALPHABETIC SYMBOLS AS A FUNCTION OF THEIR LOCATION IN THE VISUAL PERIPHERY

SHELTON MacLEOD, Ph.D.

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FOR THE COMMANDER

Charles Bates

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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A preliminary study in a proposed program of research to develop improved design criteria for peripheral vision displays was performed. Binocular peripheral identification of alphabetic symbols was measured for four subjects at four angular distances from a fixation point (3, 6, 12 and 24 degrees) and along eight equally spaced meridia in the visual field. Response measures were choice reaction time and accuracy scores. Results show: (1) a relatively constant and high level of peripheral identification along all meridia out to a 12-degree,

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angular distance from central fixation; (2) extension of this high identification performance out to 24 degrees along both right and left horizontal meridia; (3) significant differences in peripheral identifiability of the four alphabetic symbols used; (4) no significant bilateral performance differences related to dual cerebral control. An important display implication of the data concerns the potential advantage of placing letters to be identified in the periphery along the horizontal visual axis.

SUMMARY

The value of peripheral vision for the effective performance of an aircrew member is undeniable. Without the motion-produced cues at the fringes of his visual field, which reflexively direct his eyes to sources of new information, he would be unable to take effective action (destroy or outmaneuver) against sudden encroachments that threaten him from the air or ground. Or, consider the pilot who must look out of the aircraft to fixate on a critical target (runway, landmark, aiming point, etc.). His survivability could depend on his ability to simultaneously use peripherally presented cockpit information (e.g., remaining fuel, altitude, or airspeed) while his eyes remain in a foveally locked position.

The kinds of benefits afforded by peripheral vision (as exemplified by the above flight situations) need to be better understood so that critical visual factors can be systematically related to operator performance. Thus, a sound engineering basis could be provided for improving aircraft or command and control displays. Enhanced in this fashion, the display will allow the operator to take full advantage of his peripheral vision. The response time and accuracy to be gained through this kind of optimization may well make the difference between mission success or failure.

A specific example of such enhancement might entail the selective placement of peripherally viewed information in preferred sectors of the visual field. Another possible design consideration could involve the specification of an acceptably large field of view that will fully utilize motion-produced peripheral cues. Still another kind of question to be answered might be how best to enhance the image characteristics of peripherally presented symbologies (e.g., their size, shape, contrast, color) so that they may be most readily detected or recognized.

The state-of-the-art of visual handbook information is currently inadequate to provide the necessary criteria for this kind of upgrading in display design. Relevant visual research in the area of peripheral vision has simply not received the amount of attention commensurate with its importance to the Air Force.

The present report documents a preliminary effort in a program of research designed to help fill this technical gap. Although the results of the study are regarded as having some immediately useful implications for display design, like most "first-steps" there are some inherent equipment and design limitations (addressed in the Discussion) that point the way to improvement as the program advances.

PREFACE

The research reported herein was performed by the Visual Display Systems Branch, Human Engineering Division of the Aerospace Medical Research Laboratory.

The author expresses his appreciation to supporting efforts by personnel of Systems Research Laboratories, Inc.: Ms. D. Bach and Ms. J. Klug, the experimental monitors; and Mr. R. Spicuzza, Mr. A. Pinkus and Mr. S. Unger, who helped construct the apparatus.

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INTRODUCTION

Numerous situations exist where the human operator may be aided by acquiring information in peripheral vision while he maintains central fixation. He may benefit by perceiving road-side symbols as he fixates an oncoming vehicle; he may need to be warned by information displayed by one cockpit indicator while he attends to another; or, with an electro-optical device, he may have to remain visually coupled to a moving target or reticle while responding to extrafoveal information.

To use human visual perception to fullest advantage in these types of situations, additional research information is required to map the outer limits of peripheral response as this depends upon such factors as the visual characteristics of the stimulus, the region of the retina being stimulated and the type of task being performed.

The topic of peripheral vision has been studied extensively since Wertheim (1895) first demonstrated a progressive loss of visual acuity at increasing distance from the fovea. However, the scope of such studies has been limited in two important ways. First, the performance criteria have been largely restricted to relatively simple detection or acuity measures, as in the study of Kerr (1971). Second, the locations of stimuli selected for peripheral viewing have typically been limited to a single meridian of the visual field as in the research of Edwards and Goolkasian (1974).

Given these limitations, display designers lack relevant information. They must be aware of the limits of human performance in processing peripherally acquired information as dependent upon both the particular retinal region being stimulated and the nature of the visual task. Already, there is enough evidence on the interactions between these two factors to indicate that continued development of systematic information related to peripheral vision will not be a simple undertaking. Some recent efforts that have contributed to our knowledge in this area are summarized as follows.

Harcum (1960) reported that the level of visual performance is different for various meridia of the visual field, with such anisotropic effects showing further dependence on type of visual task. He stated that detection sensitivity is greatest for targets to the right and left of fixation and poorest for targets above and below fixation. Localization sensitivity, on the other hand, was equally good along both horizontal and vertical meridia, but relatively poor for targets diagonally displaced from fixation.

Using monocular measures of spatial discrimination, Wyke and Chorover (1965) found no significant performance differences between nasal and temporal hemifields for either eye. The overall performance of the left eye was found to be superior to that of the right.

Payne (1966) measured simple reaction time (RT) to monocularly presented light flashes at eccentricities (angular distances from fixation point) up to 30 degrees along various meridia. He found a decrease in RT along the horizontal meridia at about 17 degrees from the fovea (where the combined number of rods and cones are most numerous). RT to stimuli along an oblique meridian were greater than those obtained along the horizontal axis, especially for the temporal retina.

Handel and Christ (1969) specified two tasks (shape detection and identification) to be performed under conditions of nasal peripheral, temporal peripheral, and central viewing. Performance based on nasal and temporal viewing was found to be similar but different from that of central viewing. For example, in central viewing an open triangle is most often incorrectly identified as a closed triangle with the same orientation; while, at the two peripheral locations, it is most frequently misidentified as an open triangle with opposite orientation.

Another relevant consideration in mapping peripheral vision concerns functional differences between left and right cerebral hemispheres as related to the type of task being performed (Kimura, 1973). So-called analytic tasks (e.g., perceiving verbal material) are assumed to be controlled principally by the left hemisphere, while so-called spatial tasks (e.g., locating a dot in a matrix) are more subject to right hemisphere control. Such a dual system has been shown by Klatzky and Atkinson (1971), White (1971) and Gross (1972) to predictably affect the speed or accuracy of visual performance associated with stimuli appearing to the right or left of central fixation point.

Millodot and Lamont (1974) measured peripheral acuity along the lower and upper halves of the vertical viewing axis. Higher acuity was found in the lower half for eccentricities greater than five degrees.

Lefton and Haber (1974), using RT as a measure of performance, had observers make "same-different" judgments for letters at locations up to four degrees on either side of fixation along the horizontal viewing plane. Results showed that: RT increased with retinal eccentricity; performance was the same for right and left visual fields; and RTs were shorter for "same" responses close to the fovea, but, with increasing eccentricity, "different" responses became faster.

Edwards and Goolkasian (1974) determined the effects of five tasks (ranging in complexity from detection of light onset to the categorization of three-letter words) on the processing capacity of the visual periphery. Both RT and accuracy measures were recorded for presentations along the horizontal temporal visual meridian of the left eye out to an angle of 58 degrees. Other independent variables were stimulus size, luminance and duration. Although detailed conclusions of the study are too numerous to be summarized here, a rather surprising capability for complex processing was demonstrated in the periphery. At a 15-degree separation from the fovea, accuracy scores for detection, recognition and identification tasks exceeded 80% correct responses; and at 24 degrees, accuracy scores for recognition and identification still remained well above chance.

Finally, Haines *et al.* (1975) measured peripheral RT in the binocular detection of both white and colored (blue, yellow, red, green) points of light. These were presented at eccentricities ranging from 10 to 90 degrees along eight equally spaced meridia separated by 45 degrees. Iso-reaction time contours, developed from the data, extended further out horizontally than vertically and the data were related to several instrument panel/cockpit design problems.

Elements of the methodology developed in both of the last two investigations cited above provided a point of departure for the present study. The task* was alphabetic identification; binocular performance was to be measured in terms of RT and accuracy; and the peripheral locations to be stimulated extended out to the far periphery along meridia sampling the entire visual field.

*The selection of this task was dictated partly on practical grounds, in view of the immediate relevance of alphabetic symbols to visual displays; and partly on theoretical grounds, in view of the lack of knowledge about peripheral discrimination of shape differences at different eccentricities and/or sectors of the visual field.

METHOD

SUBJECTS

Four right-handed college students (three males and one female) were the experimental subjects. They had recently been subjects in other vision experiments and had been screened for normal visual acuity.

EQUIPMENT AND EXPERIMENTAL CONDITIONS

Alphabetic stimuli were presented on the rear surface of a 2-foot square Kodak Polacoat® plastic viewing screen. The screen was mounted in the center of a 4-foot square sheet of opaque material that reduced surrounding glare from ambient light and kept the experimenter, room lamps and projection system out of the subject's view.

The fixation point was provided by inserting the red illuminating tip (⅛-in. d.) of a light-emitting diode (Dialco, Diode-lite, 521-0189) through the center of the screen. The luminous intensity of this device is rated at 0.4 mcd and its peak wavelength is specified as 6500 Angstroms. Two incandescent lamps were positioned and controlled by a Variac to provde relatively uniform, low screen luminance (0.11 ft lamberts).

The stimuli were presented by a Kodak random-access 35mm slide projector. Exposure time was held to 100 msec (rise time = decay time = 6 msecs) by an attached Lafayette Model 43016 electronic shutter. This interval is short enough to preclude confounding effects of eye movements from the fixation point to the stimulus while it is being presented. At the same time it may well represent an effective stimulus duration for increasing the speed of identification. Edwards and Goolkasian (1974) found that decreasing exposure time from 1.0 to 0.2 second resulted in faster RT for the near periphery.

The projector was mounted on the platform of a tripod that could be continuously elevated and lowered in the vertical plane and rotated in the horizontal plane. Either one or a combination of these movements enabled the experimenter to project a stimulus at any predetermined point on the rear surface of the screen. The registration of projected letters at such locations was accomplished by means of a 2-foot square removable template placed over the rear surface of the screen to display the 32 circular positions (⅜-in. d.) where the letters were to be centered.

The stimuli were four alphabetic consonants: D, F, N and X. These were produced by the C-Thru Ruler Co. (M_1 Format) and were selected somewhat arbitrarily for apparent legibility and non-confusability. The letters were cut from black masks mounted to the slides so as to provide negative contrast when projected on the screen. Projected letter images were ⅜ in. high, corresponding to a vertical angular subtense of 1 degree 12 minutes with the eyes positioned 18 inches in front of the screen.

Thirty-two peripheral positions were selected. These represented four separations from the fovea (3, 6, 12 and 24 degrees) along eight meridia. The latter were separated by 45-degree angles and represented all quadrants of the visual field along the following axes: (1) right horizontal (0 degrees); (2) upper-right oblique (45 degrees); (3) upper vertical (90 degrees); (4) upper-left oblique (135 degrees); (5) left horizontal (180 degrees); (6) lower-left oblique (225 degrees); (7) lower vertical (270 degrees); and (8) lower-right oblique (315 degrees). Figure 1 shows the 32 stimulus locations.

Luminance values for the letters and their adjacent screen areas were measured by a Spectra Pritchard 1980 Photometer. Readings were taken with the photometer aimed at the screen locations through a point midway between the viewing positions of each eye. Letter luminance read in this manner decreased linearly along the vertical axis of the screen from a value of 24 ft lamberts at the 3-degree position to a value of 12 ft lamberts at 24 degrees. This falloff was attributable to angular differences in light paths from the screen to the eye. Along the horizontal axis the falloff between these two positions

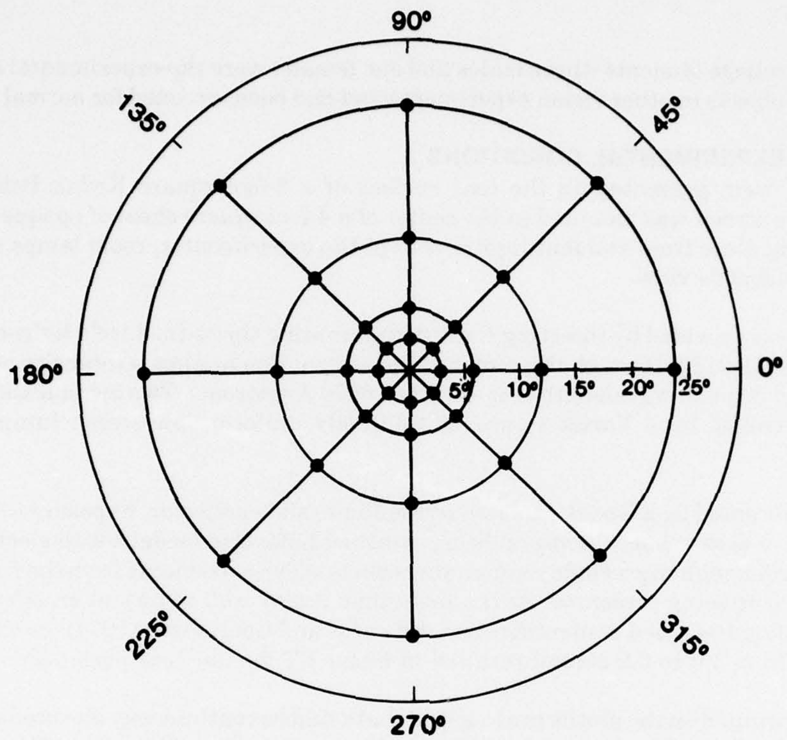

Figure 1. Thirty-Two Peripheral Locations of Experimental Stimuli (Visual Angle Scale Shown Along 0° Meridian. Meridional Angles Shown Around Outer Circumference)

was greater (i.e., from 24 to 5 ft lamberts). Contributing to this increased drop in luminance was the requirement for horizontal rotation of the projector, which increased the length of light path to the screen.

In any case, luminance contrast of the letters was considered to be a more relevant determinant of peripheral visibility than luminance per se.* Expressed by the formula:

$$L_L - B_L/L_L + B_L \times 100$$

(where L_L stands for letter luminance and B_L for the luminance of the immediately adjacent background), measures of luminance contrast for the letters were high and relatively constant, varying between 92 and 96 percent at all viewing positions.

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*Empirical support to this statement appears in the *Discussion* section of this report under *Effect of Meridian*.

The subject fixated the center of the screen with his head stabilized by a chin rest that maintained proper visual alignment with the screen at a viewing distance of 18 inches. Four response keys (Dialco, pushbutton switches, ½-in. d.) were mounted in front of the subject so as to be positioned comfortably under the second and third finger of each hand. These were labeled according to the letter whose peripheral recognition was to be signalled by pressing the switch. To control for possible positional effects, each subject was assigned a different order of letter-switch combinations so that each letter was assigned once to each position. A forced-choice method was used whereby the subject had to respond on each trial regardless of his level of uncertainty.

Both the electronic shutter and the response keys were connected to a BRS Foringer Digilab programmer interfaced with a Digitek printer. This system provided on-line digital records of all RTs in msecs in addition to errors (wrong key presses). A feedback tone reinforced each correct response.

TRIAL SEQUENCE

The following sequence of events occurred during each trial: (1) a ready-signal was voiced by the experimenter prompting the subject to assume fixation; (2) two seconds later a buzzer provided a "set" signal; (3) two seconds later the letter was flashed, the subject responded, and a correct response was reinforced; (4) six seconds later the next ready-signal was given.

PRACTICE SESSION

Before the main experiment a 45-minute practice session was provided for each subject. During this period, successive blocks of 20 trials (4 letters times 5 replications) were given in random order at one angular separation (18 degrees) for each of the eight meridia.

INSTRUCTIONS

A set of instructions * was read to each subject just before the practice session. The subject was informed of the sequence of events that would occur during a given trial. His need to maintain central fixation during the trial was stressed. He was also told to memorize the key-position for each of the four letters and to respond as fast as possible (guessing if he were not sure) with the appropriate key once he had decided which letter had been presented. Just before the first experimental session following practice he was reminded to continue responding in the same way as before and was told that successive letters would be repeatedly presented at different points on the screen.

EXPERIMENTAL SCHEDULE

There was no assurance that a single practice session would allow learning effects associated with various components of the response to level off. Therefore, the experiment was subdivided into two replicated halves (part I and part II). Data were gathered for each subject at all 32 peripheral locations during each part. This left the option of using only part II data if the responses in part I were contaminated by practice effects; or of using all the data if such effects were absent. Each part consisted of four daily 45-minute sessions during which time letters were presented at eight of the 32 positions. The specific locations of letters to be tested were randomly determined for each subject and for each session. Twenty successive trials occurred at each location. This trial block consisted of the four letters given five times in a random sequence. Subjects were given a five-minute rest break midway through the session.

*Detailed instructions appear in the appendix

SUMMARY OF EXPERIMENTAL VARIABLES AND PARAMETERS

The independent variables of the study were meridia (8 levels), visual angle,* (4 levels), and alphabetic characters (4 levels). The dependent variables were: choice reaction time, and accuracy scores (percent correct identification). Both the size and contrast of the projected letter were set at relatively high levels selected to enhance their legibility in the periphery.

STATISTICAL ANALYSIS

A 3-way within-subjects (repeated measures) analysis of variance was used to evaluate the effects of the independent variables upon each of the response measures. The .05 level of confidence was used as the criterion for establishing significance of all the F ratios and Scheffé t-tests associated with the analysis.

*Visual angle is defined in the remainder of this paper as the separation (in angular subtense) between the fixation point and the peripheral location of the stimulus.

RESULTS

PRACTICE EFFECTS

A preliminary analysis of the RT data revealed substantial practice effects occurring during the first session of part I. Mean response latencies for each subject were significantly higher (as determined by t-tests) during these early trials than for the same presentations (same combinations of letters, angles and meridia) occurring in part II. By the third session of part I no differences in RT for comparable part I and part II presentations were apparent; i.e., practice effects had leveled off. Therefore, the decision was made to consider part I as an extended practice session and to restrict experimental analysis to the data of part II.

TABULAR SUMMARY OF THE RESULTS

Table I is a descriptive summary of the results. Entries are mean performance measures (collapsed across letters) for the 32 combinations of meridia and visual angle. Each mean is based on 20 trials. Row means for meridia across visual angles, column means for visual angles across meridia, and grand means are included. The left half of the table contains RT data while the right half contains accuracy scores.

TABLE I

MEAN PERFORMANCE SCORES FOR ALPHABETIC IDENTIFICATION IN THE VISUAL PERIPHERY
(Entries Represent Four Visual Angles Along Eight Meridia)

Meridia		*Reaction Time (Msec)*					*Percent Correct Identification*				
		Visual Angles (degrees)					*Visual Angles (degrees)*				
Angle	*Direction*	*3°*	*6°*	*12°*	*24°*	*Row Means*	*3°*	*6°*	*12°*	*24°*	*Row Means*
0°	Rt. Horizontal	589	612	650	758	652	97.5	96.3	96.3	88.8	94.7
45°	Rt. Up. Oblique	603	616	646	988	713	96.3	96.3	96.3	48.8	84.4
90°	Up. Vertical	583	702	749	872	727	95.0	98.8	92.5	56.3	85.6
135°	Lft. Up. Oblique	599	589	695	1,060	763	98.8	97.5	96.3	56.3	87.2
180°	Lft. Horizontal	599	596	641	769	651	92.5	91.3	97.5	96.3	94.4
225°	Lft. Low. Oblique	608	589	670	1,063	732	96.3	100.0	96.3	66.3	89.7
270°	Low. Vertical	575	605	616	994	698	97.5	95.0	91.3	61.3	86.3
315°	Rt. Low. Oblique	572	611	677	900	690	98.8	97.5	96.3	57.5	87.5
Column Means		591	615	668	926		96.6	96.6	95.3	66.4	
Grand Means						700					88.7

EFFECT OF VISUAL ANGLE

The Analysis of Variance (ANOVA) revealed that the variable of visual angle had a highly significant main effect on both RT [$F(3, 9) = 21$, $p < .0004$] and accuracy data [$F(3.9) = 75$, $p < .0001$]. Figure 2 depicts graphic relationships between each dependent variable and visual angle. The data are pooled across meridia.

With respect to both RT and accuracy Scheffé tests show that the mean score at the 24-degree angle is significantly different (i.e. showing performance decrement) from each mean at the other three angles. However, no significant differences are to be found among any of the means representing visual angles of 3, 6 or 12 degrees.

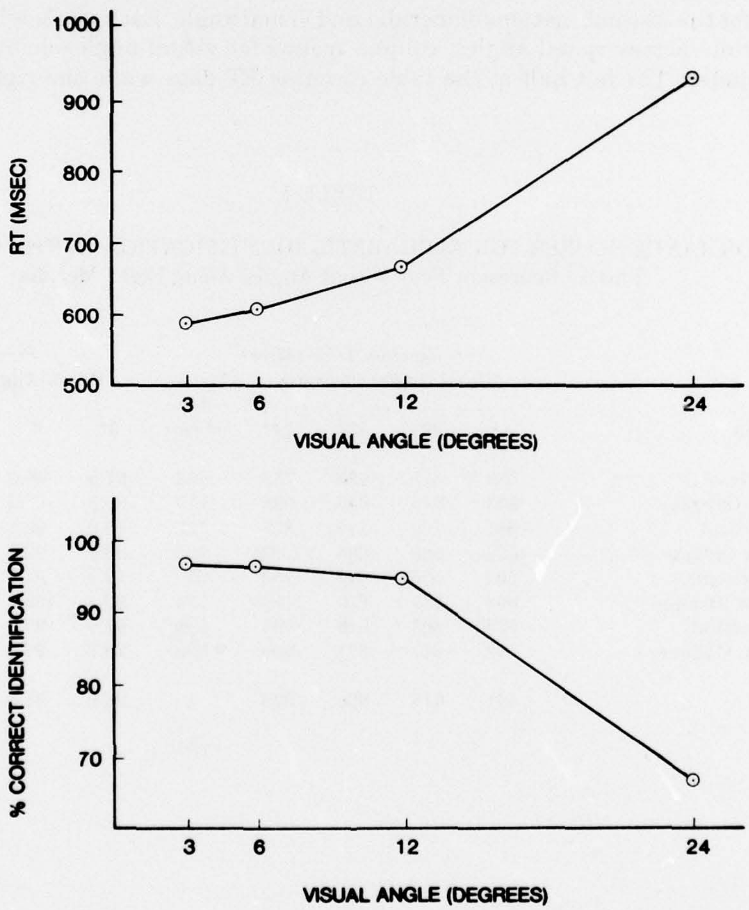

Figure 2. Relationship Between Visual Angle and Mean Performance Measures

EFFECT OF MERIDIAN

The ANOVA showed a significant main effect of meridia only for accuracy data [$F(7,21) = 7.6, 0 < .0003$]. We were interested in determining if this effect could be related to a meridian direction factor. Accordingly, Scheffé tests were again run in a three-way comparison of means for the two *horizontal* (0 and, 180 degrees), the two *vertical* (90 and, 270 degrees,) and the four *oblique* (45, 135, 225 and 315 degrees) meridia. These means have respective values of 95, 86 and 87 percent accuracy. Means for the horizontal meridia are significantly higher than those for either the vertical or oblique meridia. Differences between vertical and oblique meridia are not significant.

INTERACTION BETWEEN VISUAL ANGLE AND MERIDIAN

Significant interactions were shown in the ANOVA between visual angles and meridia for both RT [$F(21,63) = 1.7, p = .05$] and accuracy [$F(21,63) = 5.7, p < .0001$] scores. Simple effects analyses were run to determine the nature of these interactions.

Analysis of angle across meridia for RT data reveals significant simple effects [$F(3,9) \geq 3.8, p < .05$] for four of the eight meridia, these being at the 45-, 135-, 225- and 270-degree location. No significant effect of eccentricity appears at either the 0-degree or the 180-degree meridian, i.e., along the horizontal axis.

Results from this type of analysis are clearer for accuracy data. Here, highly significant simple effects [$F(3, 9)$ 16, $p < .005$] are shown along the six meridia representing the vertical and oblique axes, leaving only the right and left horizontal meridia unaffected by visual angle.

A second analysis, examining simple effects of meridia across angles, was also run for each performance measure. For RT, a highly significant effect is shown for the 24-degree field angle [$F(7, 21) = 6.3, p < .001$]. The same result is indicated even more strongly for accuracy data [$F(7, 21) = 35, p < .001$]. For the other angles (3, 6, and 12 degrees) no significant simple effects of meridia are indicated. Thus it is clear that meridia are having an impact on the data only at the 24-degree field angle.

Figure 3 (RT data) and figure 4 (accuracy data) show the interaction between visual angle and meridia. Note that the meridia have again been combined into directional groupings representing two horizontal, two vertical and four oblique orientations. Two trends indicated by the simple effects analyses are apparent on both graphs: (1) the relative flatness of the curves along the horizontal meridia, showing little deterioration in letter identification performance even at the 24-degree visual angle; (2) the overlapping curves for the 3, 6 and 12-degree angles, which diverge at the 24-degree angle, show that the effect of meridia upon letter identification performance occurs only at the largest eccentricity.

Scheffé tests were used to assess differences among the three RT and accuracy means plotted in figures 3 and 4 at the 24-degree visual angle. For each set of data, performance is significantly better (lower RT, higher accuracy) at the horizontal as compared to the oblique meridia, and no significant differences occur between vertical and oblique meridia. A significant difference between horizontal and vertical meridia also occurs for accuracy, but not for RT measures.

Scheffé tests were run (again for data at the 24-degree angle) to check for possible cerebral hemispheric effects that could produce different mean performance between the left visual field (represented by the 135-, 180- and 225-degree meridia) and the right visual field (represented by the 45-, 0- and 315-degree meridia). No significant difference between these means, representing left and right hemifields, were found for either performance measure.

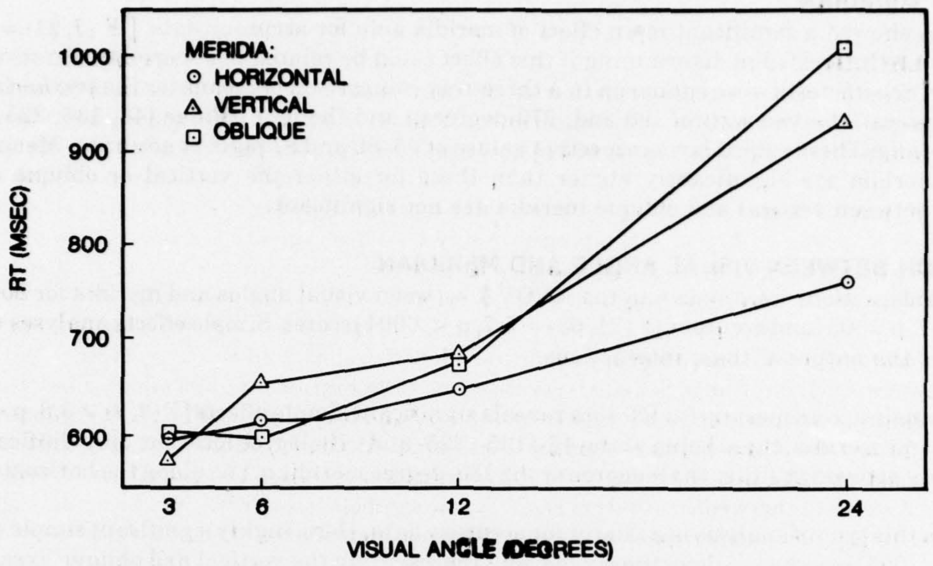

Figure 3. Mean Reaction Time as a Function of Visual Angle (Curves Show Combined Data for Horizontal, Vertical and Oblique Meridia)

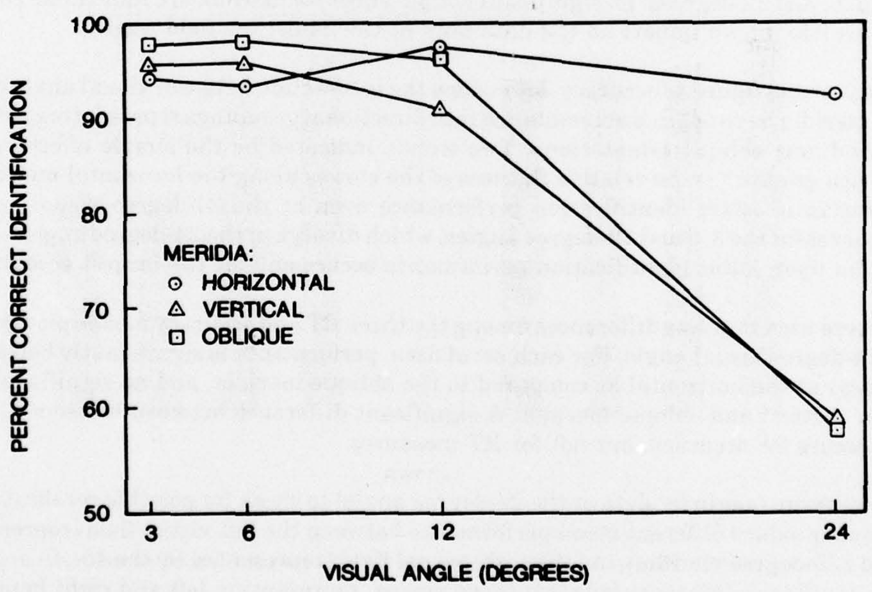

Figure 4. Mean Accuracy Scores as a Function of Visual Angle (Curves Show Combined Data for Horizontal, Vertical and Oblique Meridia)

EFFECT OF LETTER

The ANOVA showed that a significant effect of the four letters (D, F, X, N) is to be found only for accuracy scores, where, in addition to the main effect [$F(3, 9) = 4.2, p < .05$], the interaction of letters times visual angle [$F(9, 27) = 9.7, p < .0001$] also assumes significance.

An analysis of simple effects for letters across angles reveals a highly significant effect at the 24-degree visual angle [$F < (3, 9) = 17, p < .001$]. Similar analyses across the other three angles (3, 6 and 12 degrees) show no significant effects. Thus it appears that letter differences are also having an impact on performance only at the outermost angle.

Figure 5 is a histogram of mean accuracy scores for identifying each of the four letters. The left side shows means across all conditions. Scheffé tests show only two significant differences, F being correctly identified a significantly greater percentage of the time than either D or X. The right side shows mean performance for letters at the 24-degree visual field angle. At this eccentricity, letter differences are more pronounced. Scheffé tests now show significant differences for all comparisons of letter means except for the differences between the letters D and X, the symbols most difficult to recognize. The letter, F, under conditions of this experiment is clearly the most identifiable of the four symbols.

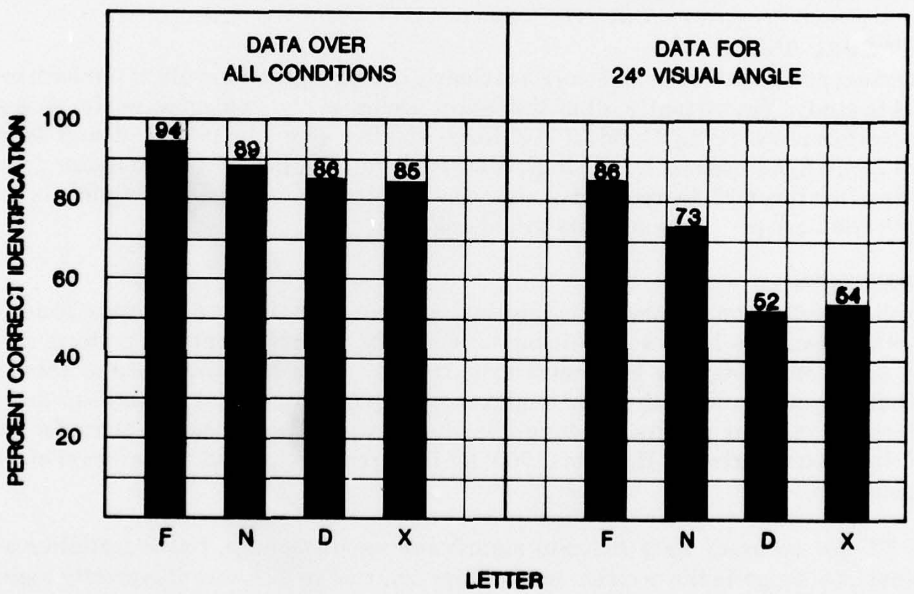

Figure 5. Mean Accuracy Scores for Letters F, N, D and X

DISCUSSION

PRACTICE EFFECT

Comparison of data from two halves of the experiment reveals an initial practice effect appearing as a reduction in the magnitude of reaction time for peripheral identification of alphabetic symbols. This effect was apparent during the first session of part I (following 160 practice trials). Such a result is not surprising since several relatively independent components of the subject's response are readily susceptible to learning. These include the maintenance of central fixation, formation of proper letter-key associations, and the correct use of cues for identifying letters in peripheral vision.

EFFECT OF ALPHANUMERIC SYMBOL

Although no attempt was made in this study to select letters differing in identifiability, a significant effect of letters did appear when measured by percent correct identification. This effect is most clearly revealed at the largest visual angle (24 degrees). The letters D and X are the most difficult to recognize while identification of the letter F is clearly superior. Although no theoretical basis has been provided in this research to explain the obtained differences, factors associated with the spatial properties of different classes of symbols and letters obviously need further study. Other recent studies of peripheral vision have revealed shape-dependent effects of symbols to be recognized in peripheral vision. These include the research of: (1) Handel and Christ (1969) whose stimuli were a set of geometric forms; (2) Menzer and Thurmond (1970) who used histoforms and polygons; and Beck (1974) who studied extrafoveal discriminability of figures in terms of their similarity grouping.

EFFECTS OF VISUAL ANGLE

Response decrement attributable to visual angle is clearly the strongest main effect (for both dependent variables) of this study. Yet virtually all of this effect occurs at the 24-degree angle, no significant differences in performance being found at the three smaller eccentricities (3, 6 and 12 degrees). However, since accuracy of response for the high-contrast, relatively large letters remains greater than 90 percent within this inner 12-degree field of view, the potential use of alphabetic symbols for display purposes within the near-periphery appears promising.

EFFECT OF MERIDIAN

Although meridional effects on peripheral recognition are more strongly revealed by the accuracy scores than by RT, both measures point to a significant outward extension of peripheral performance in both left and right directions along the horizontal axis. In fact, under the conditions of this study, no significant falloff in performance with visual angle can be demonstrated along either the 0-degree or the 180-degree meridian. Similar results, showing the superiority of the horizontal plane for peripheral viewing have also been reported by Harcum (1960) for form recognition and by Haines *et al.* (1975) for detection measures.

That neither RT nor accuracy data indicate significant impairment in letter legibility along the horizontal visual axis supports the decision to use letter contrast (which was universally high [> 90%] and relatively constant) as a more valid criterion for the identifiability of peripherally-viewed letters than letter luminance (which showed considerable falloff from the 3- to the 24-degree visual angle). Despite a sharper luminance falloff (24 to 5 ft lamberts) along the horizontal meridia, performance there was virtually unaffected, whereas significant performance decrement did occur along the vertical axis where the falloff was considerably less (24 to 12 ft lamberts). Empirical support for the conclusion that luminance is a less critical factor in peripheral than central vision comes from the studies of Edwards and Goolkasian (1974) as well as Mandelbaum and Sloan (1947).

Figures 6 and 7 show the extension of the horizontal limits for a constant level of peripheral identification performance. Using a technique similar to that of Haines *et al.* (1975), iso-response contours have been drawn showing lines of equal RT (fig. 6) and accuracy (fig. 7), within a 30-degree binocular visual field. The contours have been derived from best-fitting plots (using the method of least squares), which relate the respective performance measures to visual angle for each of the eight meridia. Linear fits were found to be reasonably descriptive for RT data; while quadratic equations were a more appropriate basis for describing the accuracy functions which (see fig. 4) are by no means linear.

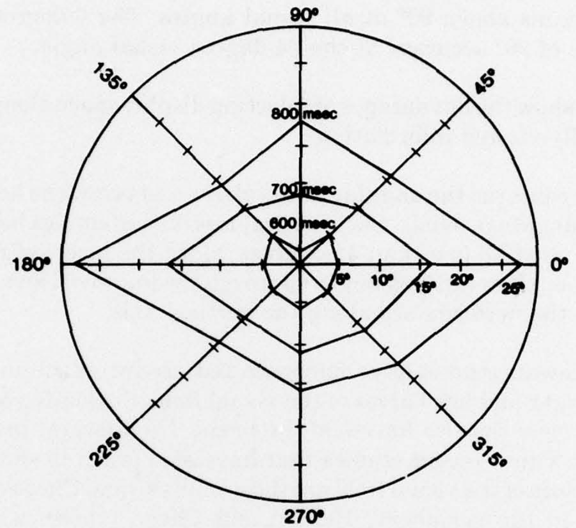

Figure 6. Iso-Reaction Time Contours (800, 700, and 600 msec) for Alphabetic Identification in Peripheral Vision (See Explanation in Text)

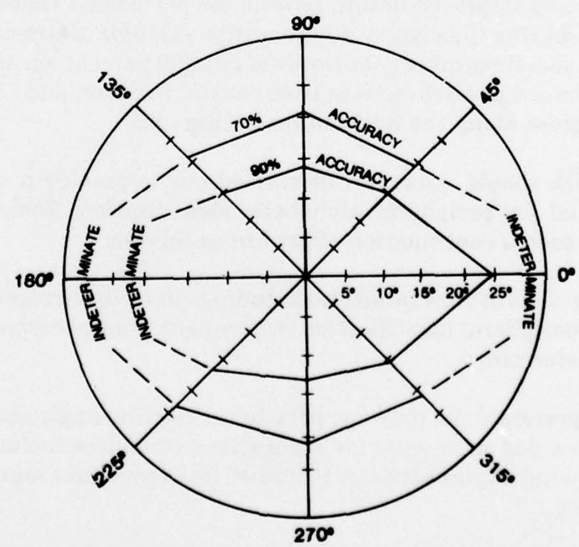

Figure 7. Iso-Accuracy Contours (90% and 70%) for Alphabetic Identification in Peripheral Vision (See Explanation in Text)

Three contours have been drawn in Figure 6 to map the boundaries within the entire visual field where reaction times of 600, 700 and 800 msec may be expected. Greater responsiveness along the horizontal dimension is indicated for the 700 and 800 msec contours by the relative compression of these lines along the vertical and oblique axes.

The same kind of relationships for accuracy measures are portrayed by the contours of figure 7, enclosing the peripheral zones where 70° and 90° correct alphabetic recognition may be expected. Here it is impossible to plot the horizontal limits for either of the contours on the left since the curve along the 180-degree meridian remains above 90° at all visual angles. The 0-degree meridian does, however permit the determination of 90° accuracy at the 24-degree visual angle.

Both illustrations clearly show the advantages of selecting display space along the horizontal visual axis for presenting peripherally-viewed information.

A related point of interest concerns the angular limits above and below the horizontal axis within which the so-called horizontal advantage exists. Such critical meridional angles have not been determined in this study. Clearly, they must be less than 45-degrees, since the levels of response along the oblique meridia are no different (i.e., show no tendency to approach the improved levels of performance along the horizontal meridia) than the performance along the vertical axis.

A number of peripheral viewing studies have demonstrated (see Introduction) task-related performance differences between the right and left halves of the visual field. Such differences have been ascribed to functional difference between the two halves of the brain. No bilateral indications of this type were found in this experiment. Other recent studies that have also failed to show performance differences between right and left sectors of the visual field are those of Wyke and Chorover (1965), who had subjects estimate linear extents in the periphery; Handel and Christ (1969), who used a geometric form recognition task; and Lefton and Haber (1974), who used same-different judgments for letters.

EXTENSION OF STUDY

As indicated in the summary, this report documents the completion of a significant "first-step" in a research program to develop improved design criteria for peripheral vision displays. The results are regarded as useful in reassuring the display designer that: (1) high-contrast alphabetic symbols can be readily identified in the visual periphery (at levels of over 90 percent accuracy) within a field of view extending 12 degrees outward in all directions from central fixation; and (2) this level of performance can persist out to 24 degrees along the horizontal viewing axis.

An extension to this work should, however, be carried out to provide a more complete and precise definition of the potential for peripheral alphabetic identification. Some desirable methodological changes to be sought in such a continuation effort are as follows:

- A sufficiently wide field of view (possibly extending out to 40 degrees) needs to be mapped so that the outer limits of peripheral identification (where performance becomes very low in all sectors of the field) can be determined.

- Judging from the present data, only one peripheral viewing angle should be sampled within ten degrees of the fovea and more angular separations should be included for the middle and far periphery (i.e., viewing angles between 15 and 40 degrees) where significant performance decrements are occurring.

- At the same time several intermediate meridional angles should be studied between the present oblique visual axes (i.e., those meridia 45 degrees from the horizontal) and the horizontal axis. This kind of sampling would establish the limits of an important functional transition (not revealed in this study; namely, the meridional falloff in performance (for visual angles greater than 12 degrees) that occurs above and below the horizontal axis.

- A meaningful physical metric should be introduced that can be used to both scale and forecast the identifiability of alphabetic symbols in terms of their spatial characteristics. I is never as satisfactory to merely discover isolated instances of letter discrimination as to provide a valid basis for predicting them. A promising possibility along these lines is a measure *d*, which represents the normalized Euclidian distance between the low spatial frequency components for two-letter patterns after these have undergone a Fourier transform. Positive relationships between *d* and psychophysical judgments of similarity for foveally-viewed letters has, in fact, already been established (Goble 1975).

- Equipment design should be modified to provide better control over experimental conditions. In particular a hemispheric screen should be used to assure equal viewing distance from all screen images to the eye. An eye-movement monitoring device (e.g., an electrooculargram) is also needed to verify that proper fixation at the center of the screen occurs on all trials.

APPENDIX

INSTRUCTIONS TO THE SUBJECTS

The following instructions were read just before the practice session:

"This experiment will test your ability to recognize alphabetic letters using peripheral vision. We will gather the necessary data at eight points in your visual field and give you a number of trials at each point. The procedure for each trial is as follows: When I say ' ready' you must immediately place your chin and head in this brace and keep both eyes fixed on this small red light. You will also place the middle and forefinger of each hand over these keys. Before we begin you will memorize the position of each letter (DFNX) on the keys so that you can press down on a given letter without looking. About 2 seconds after I say 'ready' you will hear this signal which means to get set. Then after another 2 seconds, one of the four letters will be flashed at a peripheral position on the screen. As soon as you decide which letter was presented, you are to respond as fast as possible by pressing the switch which corresponds to the letter. Sometimes you may feel that your response is a guess but you must then make your best guess as quickly as possible. Another point to be stressed concerns your fixation. After fixating the red light at the ready signal, you must hold this fixation without any eye movement until you have completed your response. Should you fail to fixate or happen to move your eyes while responding let me know and we will discount that trial. After each presentation I will pause a few seconds before giving the 'ready' signal for the next trial.

For this first session we will give you a 30-minute practice run during which we will present the letters at eight peripheral locations. You will have a 5-minute rest break halfway through the session. As you practice keep the following points in mind:

1. After deciding which of the four letters was presented, guessing if necessary, register your decision as fast as possible by depressing the appropriate key.

2. Be sure to hold fixation from the time I say 'ready' until you have responded.

"Let me know if you fail to do this."

The following additional set of instructions were added just before the first session of the main experiment:

"We are now going to start the first of eight 45-minute experimental sessions. We will follow the same procedure on each trial as we did in the practice session. The letters will be presented at one position for twenty trials. Then we will change to different positions with twenty trials at each new position. You will have a short break every time we change and a longer break halfway though the session. Are there any questions before we begin?"

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